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Challenges of Model-Based Definition for High-Value Manufacturing

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Abstract. Manufacturing Industry is moving towards adoption of 3D models as the ultimate authoritative source for complete product definition replacing 2D drawings, which is called "Model-Based Definition". Starting its journey from geometric information on design, manufacturing, and inspection, the targets are to achieve the ultimate goal of lifecycle model based enterprise, requiring MBD to be more comprehensive and challenging structure of information instead of just a geometric model. The industry has not yet fully achieved implementation of MBD to whole product lifecycle. This journey is long and tough, and we are still at an early stage, but it will be a decisive factor in gaining competitive advantage by the early adopters, especially in high-value manufacturing. Complete adoption of MBD has several issues and challenges that need to be addressed. This paper presents a review of current literature, intending to cover present state of knowledge, issues, challenges, and future research directions, in the development and adoption of MBD.

Keywords. Model-Based Definition, Model-Based Enterprise, Challenges

1. Introduction

Model-Based Definition (MBD) is a strategy to shift from paper-based 2D drawings to 3D CAD models incorporating all the product related information so that 2D drawings are no more needed [1]. The automotive and aerospace industry has already adopted the 3D model as an authoritative source of information. Though they are still using 2D drawings but the changes are made from the 3D models. Today, the advancement in CAD solutions has allowed adding functional tolerances & annotations (FT&A), thus eliminating the need for conventional 2D drawings to some extent. However, for future, product data including material, technology, and all the lifecycle is aimed to be embedded into the base 3D model to achieve a higher level of product definition in Product Lifecycle Management (PLM); to be concise-data from the requirement to retirement [2]. An MBD is a 3D digital product model that defines the requirements and specifications of the product. A Model-Based Enterprise (MBE) uses MBD to define the product requirements and specifications instead of the paper-based document as the data source for all engineering activities throughout the product lifecycle. In MBE, models are used to drive all aspects of the product lifecycle, and this data is created once and reused for all downstream activities [3].

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Product and system development were previously focused on CAD, CAE, PLM, and PDM, but this is rapidly going towards obsolescence, as the PLM was designed for a document paradigm. The discussion in high-value manufacturing now has moved towards lifecycle model-based enterprise with emerging technologies of IoT, Industrial IoT, Digital Twins and Digital Threads [4].

This journey from 2D to 3D with the aim at MBE has a lot of obstacles and challenges, and the industry has still a long way to go before getting full advantages of MBD approach. From high investments, software limitations, proprietary formats, interoperability to legacy data, security, implementation, and cultural changes, each organization has to face a lot of challenges in this journey. Though the topic is hot in the current era of industry 4.0 and the industry is experimenting fast, there is not much published research. The paper aims at figuring out the major challenges of Model-Based Definition in high-value manufacturing. It also gives a review of current literature on the Model-Based Definition and Enterprise. With conclusions, future research directions are also presented.

2. An overview of the state of the art research

There is a rapid increase in academic research in this area from 2010 onwards, though the application was started much earlier. However, in comparison to the volume and intensity of application in the modern digital manufacturing scenario and a hot topic especially in the Aerospace and Automotive sector, there is still less published research. And there is a long way to go in all of its sub-areas in the research. Currently, the research focus ranges from analyzing benefits and implications of moving towards 3D model centered processes, product definition requirements, 3D publishing in lightweight models, product data quality, CAD solutions capabilities, and introduction of plug-ins along with implementation issues. Following lines describe some of the work in this area.

A committee from American Institute of Aeronautics and Astronautics worked on Model-Based Definition [5] elaborating technical requirements of a 2D Drawing and 3D Model Data, role of MBD in the product development lifecycle and the currently available software capabilities. The paper also presented deployment examples. Finally, the authors suggested a well-defined incremental process for adoption of MBD along with an approach to formulate a business case. In an effort to test digital thread Hedberg et al. [3] defined digital thread as a combination of MBD, manufacturing, and inspection, and stated it as an enabler of real-time design and analysis, collaborative process flow development, automated artefact creation, and seamless coordination. They selected three test models involving machining process and developed both drawing & model based definition for each. After manufacturing and inspection, they measured the benefits and identified the process gaps.

Pippenger [6] reviewed the need, benefits and risks associated with 3D MBD adoption, alongside he elaborated Product & Manufacturing Information (PMI) and Quality Information Framework (QIF) features and their benefits in using downstream processes. Quintana et al. [1] made a study in Canadian aerospace, outlining the barriers in the implementation of MBD. They categorized them into the technical, process and legal issues. The authors elaborated the technical requirements of MBD in product lifecycle in terms of data content, accessibility & visualization, and data retention. Alemanni et al. [2] argue that the companies need to have a common data structure approach in a unified shape inside the native CAD model with reusability feature. Using Quality Function Deployment (QFD), the work intends to offer guidelines in developing sharable data structure for MBD for three adoption scenarios they mentioned. Hedberg et al. [7] in another work, proposed a solution to increase product data quality for its authenticity, authority and traceability. Feeny et al. [8] put an initial effort to understand the way models are used in different workflows in the industry aiming to develop a common information model out of domain-specific elements. They focused on design, manufacturing, and inspection only; leaving maintenance, sustainment and decommissioning aspects of the product lifecycle for future work. They also highlighted the challenges of adopting MBD.

Miller et al. [9] argue that there is a need to understand what and how much information is needed at each stage of the product lifecycle in defining MBD. They conducted an industrial survey capturing the present adoption status of MBD, the information needed in each of the selected workflow, the model's capability of carrying that information and finally the inhibitors of adoption. Bijnens and Cheshire [10] discussed the advantages and disadvantages of both drawing and MBD philosophies. They technically evaluated the MBD claims without bias as stated. They also discussed the current state of application of PMI semantics and the implications of use on the shop floor at the manufacturing and inspection stages.

Some efforts are done for lightweight model creation as a carrier of MBD for distribution replacing the role of 2D drawings, at the same time eliminating heavy system requirements in the downstream. In this context, Quintana et al. [11] proposed the use of MBD dataset composed of a model created by CAD application and its associated distribution file generated by a visualization application in a lightweight format. The resultant distribution file offers ease of manipulation, interrogation, and review for downstream users, thus acting as an interactive drawing. Similar work for lightweight 3D assembly instructions is done by Geng et al. [12]. They explained the difference between design PMI and assembly process oriented PMI. They proposed a method to get the advantage of 3D annotated instructions at the assembly shop floor, avoiding heavy hardware, software requirements and ease of use with a normal computer. In another work by Geng et al. [13] an effort is made to replace 2D job cards with 3D MBD job cards for Maintenance, Repair and Overhaul (MRO) for aircraft right wing disassembly.

Miller et al. [14], in another work aimed at embedding behavioural information in the MBD model, putting an initial effort to extend model based definition by introducing a plug-in for an existing CAD system. He argues that only dimensional context will not be enough in the lifecycle and the true definition lies in various domains which have to be incorporated for getting true behaviour in the digital twin context.

3. Issues and Challenges

The researchers have raised several issues in MBD development and its full implementation in order to achieve the level of MBE, in different contexts. Based on this study and some present discussions in the digital manufacturing scenario, we have identified and categorized these issues and challenges, as shown in **Figure 1** and discussed in the following lines.

3.1. Technical Issues

From the definition perspective, MBD 'essential elements' are needed to be worked upon for full realization in MBE. It is needed to have a comprehensive knowledge of information flow, as discussed by Miller [9], and there is a lack of understanding on which information is essentially needed in moving from 2D to 3D model for each workflow in the product lifecycle. Though standards have started to be set, there is still a long way to go in developing 'international standards' for model-based product definition until complete maturity to fully replace two-dimensional drawings, supported by Quintana et al. [1]. The capability of software application to fully define product data is still in the developing stage. Currently, manufacturing and inspection related information is supported by the software but to accommodate full 'lifecycle data' still a lot of technological improvements are needed. Additionally, more work on 'low-cost solutions' is needed, whether in lightweight formats or else for downstream use in order to have easy access by the vendors being unable to invest in expensive applications. MBE is not based on a single solution; rather it is a result of many applications integrated together for a common goal. The 'interoperability' issues of all these applications is a big obstacle in the realization of model-based enterprise. There is a lack of technology integration solutions as well [8].

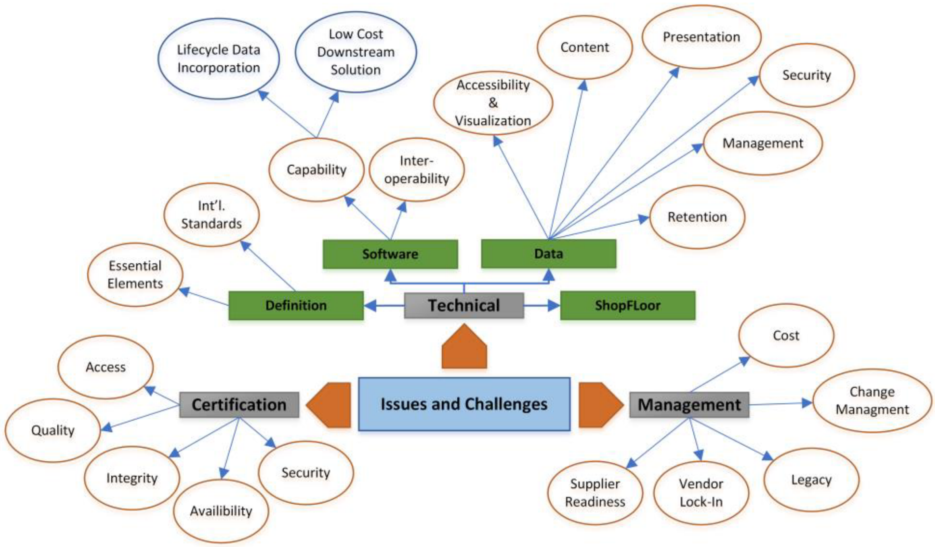

Figure 1. Issues and Challenges in MBD Implementation

Quintana [1] outlined six data-related challenges. The requirement of 'data accessibility and visualization' implies the need for visualization tools for use MBD datasets downstream. About 'data content' he argues, the downstream user has to be confident enough that MBD data set has core drawing information. In 'data presentation', like 2D drawings, there must be international standards. An appropriate method of 'data management' is necessary to manage and record revisions. He further added the 'data security' mechanism that incorporates confidentiality, authentication, integrity, and non-repudiation and finally 'data retention' capability for a long time. Similar aspects in trustworthiness, authentication, and traceability in product 'data quality' are also addressed by Hedberg et al. [7].

As far as the shop floor readiness is concerned, there are some issues pointed out by references [9] and [10]. At present, the 2D drawings are more easy to use on the shop floor. For 3D models, the hardware is required at the shop floor for visualization and process related changes in the model. If changes are not allowed at the shop floor, then these changes are to be made by the designer, putting more responsibility on design. Moreover, the capabilities of software for accommodating machining related changes are still questionable, as the neutral formats are incapable of these changes. There are only a few machines that are ready to use semantic PMI's, at inspection level only. So at first, development of user-friendly PMI's and in the future state "machine-readable PMI" is challenging for MBD.

3.2. Management Issues

For new technology adoption, there is extra investment involved [5][10]. This includes investment in software, hardware, and extra training. The adoption of MBD at enterprise level needs 'organizational change' in a well-defined manner to get full benefits, as there will be the change [5] in all business related operations and contracts with the suppliers. Pippenger [6] argues 'cultural changes' as a major barrier in implementing MBD, as all the procedures, processes and manuals are needed to be updated. There is a resistance of the workforce to adopt these changes [5]. How to convert 'legacy' design data from 2D to 3D is a big question for high-value manufacturing. It needs a lot of extra effort, time and cost [8]. The new product introduction (NPI) is a bit easier for MBD. Bijnens and Cheshire [10] stated 'Vendor Lock-In' as a major challenge. Choosing one CAD system, they stated, will lock every stakeholder in the ecosystem of the CAD vendor. This will result into uncertainty in the lifespan of the proprietary as in automotive and aerospace industry design data has to be retained for a certain period and you don't know whether the CAD vendor will be still existing till that period or not. There is a need to access supplier capabilities to suit upward MBD adoption. The supplier readiness is a challenge. Boeing, for example, has adopted a procedure for assessment of the supplier capability for MBD. It is essential for the high-value manufacturing industry to work on suppliers to fully benefit from MBD.

3.3. Certification Issues.

There are legal requirements of aerospace for retention of design for a certain period [10] in terms of data availability, accessibility, integrity, quality and security throughout the product lifecycle [1]. Similar aspects are discussed for long term archival and retrieval by Miller et al. [9]. To meet these certification requirements, MBD has a lot of issues still to be resolved.

4. Conclusions and Future Work

This work has highlighted issues and challenges affecting the implementation of Model-Based Definition in the product life cycle in various contexts. The focus was on high-value manufacturing. Three main aspects: Technical, Management and Certification are discussed along with their subfactors.

It is found that though there is a fast pace in technology and implementation, still a long journey is ahead in complete adoption and getting the status of Model-Based Enterprise. From data-related challenges to the technical improvements in definition, software, standards and implementation at shop floor level; and in organizational change management to legal issues, there are widespread challenges. Moreover, each area involves further work until complete maturity, confidence and authenticity of model-based definition.

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